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CAA-RP-89-9

GROUND, AIR, AND AIR DEFENSE FORCE CONCENTRATION MODEL

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A model for concentrating initial and subsequent ground and air forces in main-thrust sectors is developed. Timing of subsequent ground force reinforcements is then modeled. Finally, air defenses are included. These factors significantly influence force concentration outcomes. A FORTRAN program and sample results are presented.

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CAA — CONCEPTS ANALYSIS AGENCY — UNITED STATES ARMY

GROUND, AIR, AND AIR DEFENSE FORCE CONCENTRATION MODEL	STUDY SUMMARY CAA-RP-89-9

THE REASON FOR PERFORMING THE STUDY was to investigate the effect of air forces, time-phased commitment of ground forces and air defense forces on initial and subsequent force ratios in the main-thrust sectors.

THE STUDY SPONSOR was the Director, US Army Concepts Analysis Agency.

THE STUDY OBJECTIVES were to produce a mathematical model of the process and to obtain sample results.

THE SCOPE OF THE STUDY was a highly-aggregated mathematical model of forces and tactics.

THE MAIN ASSUMPTIONS of this work are:

(1) Ground forces, air forces, and air defense forces can be concentrated initially and subsequently on main-thrust sectors.

(2) A highly-aggregated mathematical model is useful in understanding this process.

THE BASIC APPROACHES used in this study were to:

(1) Develop mathematical models.

(2) Write computer programs.

(3) Explore sample problems.

THE PRINCIPAL FINDINGS of the work reported herein are as follows:

(1) Air force concentration makes a significant impact on main-thrust sector force ratios.

(2) Timing of commitment of ground forces is influential.

(3) Air defenses against air forces are influential.

THE STUDY EFFORT was directed by Jerome Bracken as an independent researcher.

COMMENTS AND QUESTIONS may be sent to the Director, US Army Concepts Analysis Agency, ATTN: CSCA-MV, 8120 Woodmont Avenue, Bethesda, Maryland 20814-2797.

Tear-out copies of this synopsis are at back cover.

CONTENTS

GROUND, AIR, AND AIR DEFENSE FORCE CONCENTRATION MODEL

A. INTRODUCTION

There are several highly-aggregated algebraic models of force concentration with have as their principal goal the analysis of the dynamics of ground, air, and air defense force ratios on main-thrust sectors. The models typically incorporate some dynamic behavior, but do not account for two-sided attrition over time.

The first model of note was that developed and applied by Research Study Group 1 of the NATO systems Science Panel VII (Reference 1). It explored ground force concentration assumptions for the attacker and defender in sectors of main attack and over the remainder of the front. To complement the representation of the indirect ground fire in Reference 1, air support and air defense were stressed in Reference 2. To highlight the importance of the dynamics of ground force reinforcement, timing issues were addressed in a series of models called FRONT, of which two recent discussions are in Reference 3 and 4. References 2, 3, and 4 build upon the work of Reference 1.

An independent derivation and evaluation of ground force concentration issues is presented in Reference 5. The model of Reference 5 determines the force ratio on the main-thrust sectors before and after reserves are committed. Reference 5 illustrates the sensitivities of main-thrust-sector force ratios to a variety of theater-wide assumptions.

More detail on the fine structure of attacker and defender position and dynamics is represented in the models of Reference 6. The issue of main concern is the identification of defense forces which possess both mobility and firepower, but do not contribute substantially to attack capability. It should be noted that a computer program, in BASIC, has been written by Wilbur B. Payne for the model of Reference 6.

The present paper focuses on the contribution of air firepower to initial and subsequent force ratios on the main-thrust sectors. This question is quite important, for the results are changed substantially when air forces are included. Because of the sensitivity of force ratios to air firepower, the present paper also develops several models which include fixed and mobile air defenses. These forces, depending on the effectiveness parameters, may significantly affect the force ratios on the sectors of main attack.

As the modeling detail is increased by adding dynamic ground force concentration, several assumptions about air force employment, and finally, several assumptions about air defenses, the equations of the model become more complicated.

The paper includes examples for the same parameters as Reference 5, plus the variations made possible by the additional forces represented in the present model. In Appendix A the FORTRAN program is presented; it matches the mathematical formulas of the main body of the paper. In Appendix B sample force ratios are given for a spectrum of assumptions on ground and air forces.

B. GROUND-AIR MODEL

1. Definition

The notation is an extension of that of Reference 5.

a. Inputs

A = attacker ground forces

$\bar{A}$ = attacker air forces

D = defender ground forces

$\bar{D}$ = defender air forces

R = defender fraction ground forces in reserve

$\bar{R}$ = defender fraction air forces in reserve

R' = attacker fraction ground forces in reserve

$\bar{R}'$ = attacker fraction air forces in reserve

s = number of sectors

t = number of main-thrust sectors

h = force ratio to be tolerated by attacker in non-main-thrust sectors

b. Outputs

C = force ratio in main-thrust sectors before reserves committed.

C' = force ratio in main-thrust sectors after reserves committed.

2. Description of Process

The attacker has ground forces A of which he initially commits fraction $(1-R')$. The defender has ground forces D of which he initially commits fraction (1-R). The attacker, in the non-main-thrust sectors, matches fraction h of the defender's forces (for instance, the attacker may set $h = \frac{2}{3}$). The defender's forces are assumed to be uniformly committed. The attacker, in the main-thrust sectors, concentrates the rest. This results in the initial force ratio C.

Then both sides commit their reserves to the main-thrust sectors. This results in force ratio C'.

Typically, the attacker fraction held in reserve is smaller than the defender's fraction held in reserve (for instance, $R' = 1/6$ while $R = 1/3$). Initial force ratio C is typically much greater than subsequent force ratio C'.

Air forces added to the ground forces are A and D, with reserve fractions R' and R, respectively.

In Model 1 it is assumed that initially committed air is uniformly spaced across the theater (except for the attacker's excess after meeting the h fraction). In Model 2, it is assumed that initially committed air is concentrated in the main-thrust sectors. In both Model 1 and Model 2, subsequent air is concentrated in the main-thrust sectors.

3. Models

Model 1 - Air initially committed to all sectors

$$C = \frac{A + \overline{A} - h\left(\frac{s-t}{s}\right)\left[(1-R)D + (1-\overline{R})\overline{D}\right] - R'A - \overline{R'}\,\overline{A}}{\left(\frac{t}{s}\right)\left[(1-R)D + (1-\overline{R})\overline{D}\right]}$$

$$C' = \frac{A + \overline{A} - h\left(\frac{s-t}{s}\right)\left[(1-R)D + (1-\overline{R})\overline{D}\right]}{\left(\frac{t}{s}\right)\left[(1-R)D + (1-\overline{R})\overline{D}\right] + RD + \overline{R}\,\overline{D}}$$

Model 2 - Air initially committed to main-thrust sectors only

$$C = \frac{A + \overline{A} - h\left(\frac{s-t}{s}\right)(1-R)D - R'A - \overline{R'}\,\overline{A}}{\left(\frac{t}{s}\right)(1-R)D + (1-\overline{R})\overline{D}}$$

$$C' = \frac{A + \overline{A} - h\left(\frac{s-t}{s}\right)(1-R)D}{\left(\frac{t}{s}\right)(1-R)D + (1-\overline{R})\overline{D} + RD + \overline{R}\,\overline{D}}$$

4. Example Problem

a. Parameters - Model 1 and Model 2

$$R = 1/3$$

$$\overline{R} = 1/2$$

$$R' = 1/6$$

$$\overline{R'} = 1/2$$

$$s = 9$$

$$t = 2$$

$$h = 2/3$$

b. Sample Results

Case	Models	A	$\overline{A}$	D	$\overline{D}$	C	C′
1	Models 1 and 2*	1	0	1	0	3.29	1.36
2	Model 1	2	1	2	1	2.98	1.30
3	Model 2	2	1	2	1	1.85	1.18
4	Models 1 and 2*	3	0	2	0	6.10	2.40
5	Model 1	3	1	2	1	5.03	1.94
6	Model 2	3	1	2	1	2.90	1.69

*Model 1 and Model 2 give the same results when there is no air.

c. Dramatic Result

Compare Case 4 with Case 6.

Ground forces only in Case 4 result in initial force ratio 6.10 and subsequent force ratio 2.40 in the two main-thrust sectors. However, when air forces are added, and concentrated by the attacker and defender in the main-thrust sectors, the initial and subsequent force ratios are reduced to 2.90 and 1.69, respectively.

C. EXTENSION TO INCLUDE TIME-PHASED COMMITMENT OF GROUND FORCE RESERVES

1. Assumptions

Assume that ground force reinforcement speeds differ for the attacker and defender. Define

r_i = defender fraction of reserves available in main-thrust sectors by period i

r'_i = attacker fraction of reserves available in main-thrust sectors by period i

Sample parameters are as follows:

$$r_1 = 0 \qquad r_1' = 0$$

$$r_2 = .1 \qquad r_2' = .3$$

$$r_3 = .4 \qquad r_3' = .8$$

$$r_4 = 1 \qquad r_4' = 1$$

Define

C'_i = force ratio on main-thrust sectors at period i of reserve ground forces arrival.

2. Models

The revised models are as follows. C does not change; C'_i includes the index i and new terms in the numerator and denominator.

Model 1 - Air initially committed to all sectors

$$C = \frac{A + \overline{A} - h\left(\frac{s-t}{s}\right)\left[(1-R)D + (1-\overline{R})\overline{D}\right] - R'A - \overline{R'}\,\overline{A}}{\left(\frac{t}{s}\right)\left[(1-R)D + (1-\overline{R})\overline{D}\right]}$$

$$C'_i = \frac{A + \overline{A} - h\left(\frac{s-t}{s}\right)\left[(1-R)D + (1-\overline{R})\overline{D}\right] - (1-r_i')R'A}{\left(\frac{t}{s}\right)\left[(1-R)D + (1-\overline{R})\overline{D}\right] + r_i RD + \overline{R}\,\overline{D}}$$

Model 2 - Air initially committed to main-thrust sectors only

$$C = \frac{A + \overline{A} - h\left(\frac{s-t}{s}\right)(1-R)D - R'A - \overline{R'}\,\overline{A}}{\left(\frac{t}{s}\right)(1-R)D + (1-\overline{R})\overline{D}}$$

$$C'_i = \frac{A + \overline{A} - h\left(\frac{s-t}{s}\right)(1-R)D - (1-r_i')R'A}{\left(\frac{t}{s}\right)(1-R)D + (1-\overline{R})\overline{D} + r_i RD + \overline{R}\,\overline{D}}$$

3. Sample Results

Sample results for the previous example, expanded, are given at the top of the next page.

Case	Models	A	$\bar{A}$	D	$\bar{D}$	C	C'_1	C'_2	C'_3	C'_4
1	Models 1 and 2	1	0	1	0	3.29	3.29	2.96	2.21	1.36
2	Model 1	2	1	2	1	2.98	1.89	1.86	1.69	1.30
3	Model 2	2	1	2	1	1.85	1.52	1.52	1.43	1.18
4	Models 1 and 2	3	0	2	0	6.10	6.10	5.40	3.92	2.40
5	Model 1	3	1	2	1	5.03	2.81	2.77	2.51	1.94
6	Model 2	3	1	2	1	2.90	2.17	2.17	2.05	1.69

Note that, though not appearing in this example, it is possible for C'_i to increase during the interim periods (for instance, from C'_1 to C'_2) if the attacker reserves are committed sufficiently faster than the defender reserves, even if the attacker reserves are smaller.

D. EXTENSION TO INCLUDE AIR DEFENSES

1. Introduction

Definitions are presented, accompanied by assumptions. The revised model is given. Results are presented.

2. Definitions and Assumptions

Define

k_f, k_m = kill of attacker air firepower per unit of fixed and mobile defender ground forces

l_f, l_m = kill of defender air firepower per unit of fixed and mobile attackers ground forces

Assume that defender initial ground forces with their air defenses are uniformly deployed. Assume that defender reserve ground forces with their air defenses arrive at main-thrust sectors.

Assume that attacker initial ground forces have their air defenses deployed in proportion p_{mt} in the main-thrust sectors and $(1 - p_{mt})$ in the non-main-thrust sectors. Assume that attacker reserve ground forces with their air defenses arrive at the main-thrust sectors.

3. Models

These models are extensions of the previous models. They are given in a different format, however, to facilitate understanding.

The primary difficulty with adding air defense to the models is that firepower killed by air defenses cannot exceed firepower of the air forces being killed. Thus, many max (term, 0) expressions appear.

Model 1 - Air initially committed to all sectors and subsequently committed to main-thrust sectors

0. Defender ground and air firepower in non-main-thrust sectors

$$T_0 = \left(\frac{s-t}{s}\right)(D - RD) + max\left\{\left|\left(\frac{s-t}{s}\right)(\overline{D} - \overline{R}\,\overline{D}) - (1 - p_{mt})l_f(A - R'A)\right|, 0\right\}$$

1. Attacker ground and air firepower in main-thrust sectors

$$T_1 = (A - R'A) + max\left\{\left|(\overline{A} - \overline{R'}\,\overline{A}) - k_f\left(\frac{t}{s}\right)(D - RD)\right|, 0\right\} - h\,T_0$$

2. Defender ground and air firepower in main-thrust sectors

$$T_2 = \left(\frac{t}{s}\right)(D - RD) + max\left\{\left|\left(\frac{t}{s}\right)(\overline{D} - \overline{R}\,\overline{D}) - p_{mt}\,l_f(A - R'A)\right|, 0\right\}$$

Initial Force Ratio

$$C = \frac{T_1}{T_2}$$

3. Attacker ground and air firepower in main-thrust sectors

$$T_{3_i} = (A - R'A) + r'_i R'A + max\left\{\left|(\overline{A} - \overline{R'}\,\overline{A}) + \overline{R'}\,\overline{A} - k_f\left(\frac{t}{s}\right)(D - RD) - k_m r_i RD\right|, 0\right\} - h\,T_0$$

4. Defender ground and air firepower in main-thrust sectors

$$T_{4_i} = \left(\frac{t}{s}\right)(D - RD) + r_i RD + max\left\{\left|\left(\frac{t}{s}\right)(\overline{D} - \overline{R}\,\overline{D}) - p_{mt} l_f (A - R'A) - l_m r_i' R'A\right|, 0\right\}$$

Subsequent Force Ratios

$$C_i' = \frac{T_{3_i}}{T_{4_i}}$$

Model 2 - Air initially committed to main-thrust sectors and subsequently committed to main-thrust sectors

1. Attacker ground and air firepower in main-thrust sectors. (Note: it is assumed here that attacker knows that defender does not commit air to non-main-thrust sectors; thus, attacker only needs to tie down h times ground force firepower.

$$T_1 = (A - R'A) + max\left\{\left|(\overline{A} - \overline{R'}\,\overline{A}) - k_f\left(\frac{t}{s}\right)(D - RD)\right|, 0\right\} - h\left(\frac{s - t}{s}\right)(D - RD)$$

2. Defender ground and air firepower in main-thrust sectors

$$T_2 = \left(\frac{t}{s}\right)(D - RD) + max\left\{\left|\left(\frac{t}{s}\right)(\overline{D} - \overline{R}\,\overline{D}) - p_{mt} l_f (A - R'A)\right|, 0\right\}$$

Initial Force Ratio

$$C = \frac{T_1}{T_2}$$

3. Attacker ground and air firepower in main-thrust sectors

$$T_{3_t} = (A - R'A) + r'_t R'A + max\left\{ \left| (\overline{A} - \overline{R'}\,\overline{A}) + \overline{R'}\,\overline{A} - k_f\left(\frac{t}{s}\right)(D - RD) - k_m r_t RD \right|, 0 \right\}$$

$$- h\left(\frac{s-t}{s}\right)(1 - R)D$$

4. Defender ground and air firepower in main-thrust sectors

$$T_{4_t} = \left(\frac{t}{s}\right)(D - RD) + r_t RD + max\left\{ \left| \left(\frac{t}{s}\right)(\overline{D} - \overline{R}\,\overline{D}) + \overline{R}\,\overline{D} - p_{mt} l_f (A - R'A) - l_m r'_t R'A \right|, 0 \right\}$$

Subsequent Force Ratios

$$C_t' = \frac{T_{3_t}}{T_{4_t}}$$

4. Sample Results

The following results are for two force structures which have different amounts of defending ground and air forces. Variations in air defense parameters are made and initial and final main-thrust sector force ratios are displayed. Results are sensitive to air defense parameters.

Force structures				Air defense parameters					Results			
									Model 1		Model 2	
A	$\bar{A}$	D	$\bar{D}$	k_f	k_m	l_f	l_m	p_{mt}	C	C'_4	C	C'_4
4	1	3	1	0	0	0	0	.5	4.57	1.80	2.96	1.62
4	1	2	2	0	0	0	0	.5	5.06	1.73	2.42	1.45
4	1	3	1	.1	.1	.1	.1	.5	5.86	2.01	3.54	1.73
4	1	2	2	1	.1	.1	.1	.5	7.69	1.95	2.76	1.54
4	1	3	1	2	.2	.2	.2	.5	6.01	2.29	4.43	1.86
4	1	2	2	.2	.2	.2	.2	.5	9.40	2.22	3.20	1.65
4	1	3	1	.3	.3	.3	.3	.5	5.99	2.44	5.99	2.02
4	1	2	2	.3	.3	.3	.3	.5	9.68	2.58	3.83	1.78
4	1	3	1	.3	.1	.3	.1	.5	5.99	2.50	5.99	1.99
4	1	2	2	.3	.1	.3	.1	.5	9.68	2.45	3.83	1.73

E. REFFRENCES

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APPENDIX A

FORTRAN PROGRAM

```
C
C --- FORCE CONCENTRATION MODEL
C
      PROGRAM FCM
C
  5   FORMAT(1X,'A,AB,D,DB,C,CP(1),CP(2),CP(3),CP(4)')
  6   FORMAT(4F5.0,3X,F8.2,3X,4F8.2)
  7   FORMAT(4F5.1,3X,F8.2,3X,4F8.2)
C
 11   FORMAT(1X,'MODEL 1')
 12   FORMAT(1X,'MODEL 2')
C
      DIMENSION RS(4),RPS(4),CP(4)
C
      OPEN (6,FILE='6.OUT',STATUS='NEW')
      OPEN (7,FILE='7.OUT',STATUS='NEW')
C
C --- FIRST SET OF PARAMETERS (SECTION B OF DOCUMENT)
C
C     R = DEFENDER FRACTION GROUND FORCES IN RESERVE
C     RB = DEFENDER FRACTION AIR FORCES IN RESERVE
C     RP = ATTACKER FRACTION GROUND FORCES IN RESERVE
C     RPB = ATTACKER FRACTION AIR FORCES IN RESERVE
C     S = NUMBER OF SECTORS
C     T = NUMBER OF MAIN THRUST SECTORS
C     H = FORCE RATIO TO BE TOLERATED BY ATTACKER ON NON-MAIN-THRUST
C         SECTORS
C
      R=1./3.
      RB=1./2.
      RP=1./6.
      RBP=1./2.
      S=9.
      T=2.
      H=2./3.
C
C --- SECOND SET OF PARAMETERS (SECTION C OF DOCUMENT)
C
C     RS(I) = DEFENDER FRACTION OF RESERVES AVAILABLE IN MAIN-THRUST
C             SECTORS BY PERIOD I (I=1 TO 4)
C     RPS(I) = ATTACKER FRACTION OF RESERVES AVAILABLE IN MAIN-THRUST
C              SECTORS BY PERIOD I (I=1 TO 4)
C
      RS(1)=0.
      RS(2)=.1
      RS(3)=.4
      RS(4)=1.
      RPS(1)=0.
      RPS(2)=.3
      RPS(3)=.8
      RPS(4)=1.
C
C --- THIRD SET OF PARAMETERS (SECTION D OF DOCUMENT)
C
C     FKF = KILL OF ATTACKER AIR FIREPOWER PER UNIT OF FIXED
C           DEFENDER GROUND FORCES
C     FKM = KILL OF ATTACKER AIR FIREPOWER PER UNIT OF MOBILE
C           DEFENDER GROUND FORCES
```

```
C      FLF = KILL OF DEFENDER AIR FIREPOWER PER UNIT OF FIXED
             ATTACKER GROUND FORCES
C      FLM = KILL OF DEFENDER AIR FIREPOWER PER UNIT OF MOBILE
             ATTACKER GROUND FORCES
C      PMT = FRACTION OF ATTACKER AIR DEFENSES INITIALLY DEPLOYED TO
             MAIN-THRUST SECTORS
C
       FKF=.1
       FKM=.1
       FLF=.1
       FLM=.1
       PMT=.5
C
C --- MODEL 1 (AIR INITIALLY COMMITTED TO ALL SECTORS)
C
       WRITE(6,11)
       WRITE(6,5)
C
C --- LOOP ON GROUND AND AIR PARAMETERS
C
       DO 100 IA=1,4
       IABM=IA+1
       DO 100 IAB=1,IABM
       DO 100 ID=1,IA
       IDBM=ID+1
       DO 100 IDB=1,IDBM
C
       A=IA
       AB=IAB-1
       D=ID
       DB=IDB-1
C
C --- TERM ZERO
C
       TZ= ((S-T)/S) * (D-R*D)
      X    + MAX ( (  ((S-T)/S) * (DB-RB*DB)
      X                - (1.-PMT) * FLF * (A-RP*A)  ) , 0. )
C
C --- TERM ONE
C
       T1 = (A-RP*A)
      X     + MAX ( ( (AB-RBP*AB)
      X                - FKF * (T/S) * (D-R*D) ) ,0.)
      X     - H* TZ
C
C --- TERM TWO
C
       T2 = (T/S) * (D-R*D)
      X     + MAX ( ( (T/S) * (DB-RB*DB)
      X               - PMT * FLF * (A-RP*A) ), 0.)
C
C --- INITIAL FORCE RATIO
C
       C=T1/T2
C
       DO 90 I=1,4
C
C --- TERM THREE
```

```
C
       T3 = ( A-RP*A) + RPS(I)*RP*A
     X      + MAX ( ( (AB-RBP*AB) + RBP*AB
     X                - FKF * (T/S)*(D-R*D)
     X                - FKM * RS(I)*R*D   ), 0. )
     X      - H * TZ
C
C --- TERM FOUR
C
       T4 = (T/S) * (D-R*D) + RS(I)*R*D
     X      + MAX ( ( (T/S)*(DB-RB*DB) + RB*DB
     X              - PMT * FLF * (A-RP*A)
     X              - FLM * RPS(I)*RP*A  ), 0.)
C
C --- SUBSEQUENT FORCE RATIO I
C
       CP(I)=T3/T4
C
 90    CONTINUE
C
       WRITE(6,6) A,AB,D,DB,C,CP(1),CP(2),CP(3),CP(4)
C
 100   CONTINUE
C
C --- MODEL 2 (AIR INITIALLY COMMITTED TO MAIN-THRUST SECTORS ONLY)
C
       WRITE(7,12)
       WRITE(7,5)
C
C --- LOOP ON GROUND AND AIR FORCES
C
       DO 200 IA=1,4
       IABM=IA+1
       DO 200 IAB=1,IABM
       DO 200 ID=1,IA
       IDBM=ID+1
       DO 200 IDB=1,IDBM
C
       A=IA
       AB=IAB-1
       D=ID
       DB=IDB-1
C
C --- TERM ONE
C
       T1 = (A-RP*A)
     X      + MAX ( ( (AB-RBP*AB)
     X               - FKF * (T/S) * (D-R*D) ) ,0.)
     X      - H * ((S-T)/S) * (D-R*D)
C
C --- TERM TWO
C
       T2 = (T/S) * (D-R*D)
     X      + MAX ( ( (DB-RB*DB)
     X              - PMT * FLF * (A-RP*A) ), 0.)
C
C --- INITIAL FORCE RATIO
C
```

```
         C=T1/T2
C
         DO 190 I=1,4
C
C --- TERM THREE
C
         T3 = ( A-RP*A) + RPS(I)*RP*A
     X        + MAX (   ( (AB-RBP*AB) + RBP*AB
     X                      - FKF * (T/S)*(D-R*D)
     X                      - FKM * RS(I)*R*D    ), 0. )
     X        - H *   ( (S-T)/S) * (D-R*D)
C
C --- TERM FOUR
C
         T4 = (T/S) * (D-R*D) + RS(I)*R*D
     X        + MAX ( ( (DB-RB*DB) + RB*DB
     X                    - PMT * FLF * (A-RP*A)
     X                    - FLM * RPS(I)*RP*A   ), 0.)
C
C --- SUBSEQUENT FORCE RATIO I
C
         CP(I)=T3/T4
C
  190    CONTINUE
C
         WRITE(7,6) A,AB,D,DB,C,CP(1),CP(2),CP(3),CP(4)
C
  200    CONTINUE
C
         STOP
         END
```

APPENDIX B

SAMPLE OUTPUT

Results are given for Model and Model 2. They are produced by the FORTRAN program of Appendix A.

The following are tabulated:

A = attacker ground forces (A)

$\bar{A}$ = attacker air forces (AB)

D = defender ground forces (D)

$\bar{D}$ = defender air forces (DB)

C = initial force ratio in main-thrust sectors before reserve committed (C)

C'_i = subsequent force ratios main-threat sectors at periods i = 1, 2, 3, 4 of ground forces arrival (CP(1), CP(2), CP(3), CP(4))

A is varied from 1 to 4. D is varied from 1 to A. $\bar{A}$ and $\bar{D}$ are varied from 0 to A.

MODEL 1

A,AB,D,DB,C,CP(1),CP(2),CP(3),CP(4)

A	AB	D	DB	C	CP(1)	CP(2)	CP(3)	CP(4)
1.	0.	1.	0.	3.29	3.29	2.96	2.21	1.36
1.	0.	1.	1.	1.18	.36	.41	.47	.41
1.	1.	1.	0.	6.57	9.94	8.37	5.66	3.34
1.	1.	1.	1.	3.41	1.73	1.73	1.63	1.33
2.	0.	1.	0.	8.92	8.92	7.83	5.64	3.44
2.	0.	1.	1.	6.35	1.65	1.74	1.77	1.49
2.	0.	2.	0.	3.29	3.29	2.96	2.21	1.36
2.	0.	2.	1.	2.38	.94	.99	.98	.76
2.	0.	2.	2.	1.18	.36	.41	.47	.41
2.	1.	1.	0.	12.19	15.57	13.24	9.09	5.41
2.	1.	1.	1.	9.11	3.11	3.14	3.01	2.46
2.	1.	2.	0.	4.88	6.57	5.62	3.88	2.30
2.	1.	2.	1.	3.83	2.11	2.08	1.86	1.38
2.	1.	2.	2.	2.26	1.03	1.06	1.03	.85
2.	2.	1.	0.	15.57	22.32	18.75	12.65	7.49
2.	2.	1.	1.	11.95	4.59	4.58	4.29	3.49
2.	2.	2.	0.	6.57	9.94	8.37	5.66	3.34
2.	2.	2.	1.	5.38	3.33	3.22	2.80	2.06
2.	2.	2.	2.	3.41	1.73	1.73	1.63	1.33
3.	0.	1.	0.	14.54	14.54	12.70	9.07	5.51
3.	0.	1.	1.	13.35	3.12	3.26	3.27	2.70
3.	0.	2.	0.	6.10	6.10	5.40	3.92	2.40
3.	0.	2.	1.	5.51	2.09	2.14	2.01	1.52
3.	0.	2.	2.	3.49	.99	1.05	1.09	.93
3.	0.	3.	0.	3.29	3.29	2.96	2.21	1.36
3.	0.	3.	1.	2.90	1.38	1.42	1.31	.95
3.	0.	3.	2.	1.90	.67	.72	.75	.61
3.	0.	3.	3.	1.18	.36	.41	.47	.41
3.	1.	1.	0.	17.82	21.19	18.11	12.53	7.49
3.	1.	1.	1.	16.63	4.67	4.77	4.60	3.74
3.	1.	2.	0.	7.69	9.38	8.05	5.60	3.34
3.	1.	2.	1.	7.10	3.33	3.29	2.95	2.17
3.	1.	2.	2.	4.69	1.68	1.72	1.68	1.38
3.	1.	3.	0.	4.32	5.44	4.70	3.29	1.95
3.	1.	3.	1.	3.92	2.41	2.35	2.02	1.41
3.	1.	3.	2.	2.74	1.29	1.31	1.23	.96
3.	1.	3.	3.	1.88	.80	.83	.83	.68
3.	2.	1.	0.	21.19	27.94	23.62	16.08	9.57
3.	2.	1.	1.	20.00	6.25	6.30	5.98	4.83
3.	2.	2.	0.	9.38	12.75	10.81	7.38	4.37
3.	2.	2.	1.	8.79	4.61	4.49	3.94	2.89
3.	2.	2.	2.	5.96	2.40	2.41	2.29	1.88
3.	2.	3.	0.	5.44	7.69	6.54	4.47	2.64
3.	2.	3.	1.	5.05	3.48	3.33	2.79	1.94
3.	2.	3.	2.	3.66	1.94	1.92	1.76	1.36
3.	2.	3.	3.	2.64	1.27	1.28	1.23	1.01
3.	3.	1.	0.	24.57	34.69	29.13	19.63	11.64
3.	3.	1.	1.	23.38	7.83	7.83	7.35	5.92
3.	3.	2.	0.	11.07	16.13	13.56	9.15	5.41
3.	3.	2.	1.	10.47	5.88	5.69	4.93	3.60
3.	3.	2.	2.	7.23	3.12	3.10	2.91	2.38
3.	3.	3.	0.	6.57	9.94	8.37	5.66	3.34
3.	3.	3.	1.	6.17	4.56	4.32	3.57	2.47
3.	3.	3.	2.	4.58	2.58	2.53	2.28	1.76
3.	3.	3.	3.	3.41	1.73	1.73	1.63	1.33
4.	0.	1.	0.	20.17	20.17	17.56	12.51	7.59
4.	0.	1.	1.	19.17	4.79	5.02	5.01	4.08
4.	0.	2.	0.	8.92	8.92	7.83	5.64	3.44
4.	0.	2.	1.	8.42	3.37	3.42	3.17	2.36
4.	0.	2.	2.	6.35	1.65	1.74	1.77	1.49
4.	0.	3.	0.	5.17	5.17	4.59	3.35	2.05
4.	0.	3.	1.	4.83	2.42	2.42	2.17	1.54
4.	0.	3.	2.	3.78	1.26	1.32	1.31	1.05

4.	0.	3.	3.	2.67	.77	.84	.88	.75
4.	0.	4.	0.	3.29	3.29	2.96	2.21	1.36
4.	0.	4.	1.	3.04	1.74	1.74	1.54	1.07
4.	0.	4.	2.	2.38	.94	.99	.98	.76
4.	0.	4.	3.	1.69	.57	.63	.66	.55
4.	0.	4.	4.	1.18	.36	.41	.47	.41
4.	1.	1.	0.	23.44	26.82	22.97	15.96	9.57
4.	1.	1.	1.	22.44	6.45	6.64	6.46	5.19
4.	1.	2.	0.	10.50	12.19	10.49	7.32	4.37
4.	1.	2.	1.	10.00	4.68	4.65	4.16	3.03
4.	1.	2.	2.	7.69	2.37	2.43	2.37	1.95
4.	1.	3.	0.	6.19	7.32	6.32	4.44	2.6[illegible]
4.	1.	3.	1.	5.86	3.49	3.40	2.91	2.01
4.	1.	3.	2.	4.69	1.90	1.92	1.81	1.40
4.	1.	3.	3.	3.41	1.22	1.27	1.25	1.04
4.	1.	4.	0.	4.04	4.88	4.24	2.99	1.78
4.	1.	4.	1.	3.79	2.65	2.55	2.12	1.42
4.	1.	4.	2.	3.06	1.51	1.52	1.39	1.04
4.	1.	4.	3.	2.27	.98	1.02	.99	.78
4.	1.	4.	4.	1.68	.68	.72	.73	.60
4.	2.	1.	0.	26.82	33.57	28.49	19.51	11.64
4.	2.	1.	1.	25.82	8.14	8.29	7.95	6.35
4.	2.	2.	0.	12.19	15.57	13.24	9.09	5.41
4.	2.	2.	1.	11.69	6.03	5.92	5.21	3.78
4.	2.	2.	2.	9.11	3.11	3.14	3.01	2.46
4.	2.	3.	0.	7.32	9.57	8.16	5.62	3.34
4.	2.	3.	1.	6.98	4.62	4.43	3.72	2.56
4.	2.	3.	2.	5.69	2.56	2.55	2.35	1.81
4.	2.	3.	3.	4.23	1.70	1.72	1.66	1.36
4.	2.	4.	0.	4.88	6.57	5.62	3.88	2.30
4.	2.	4.	1.	4.63	3.61	3.42	2.78	1.86
4.	2.	4.	2.	3.83	2.11	2.08	1.86	1.38
4.	2.	4.	3.	2.93	1.43	1.44	1.35	1.07
4.	2.	4.	4.	2.26	1.03	1.06	1.03	.85
4.	3.	1.	0.	30.19	40.32	34.00	23.07	13.72
4.	3.	1.	1.	29.19	9.83	9.94	9.43	7.52
4.	3.	2.	0.	13.88	18.94	16.00	10.87	6.45
4.	3.	2.	1.	13.38	7.38	7.19	6.26	4.52
4.	3.	2.	2.	10.53	3.85	3.86	3.65	2.97
4.	3.	3.	0.	8.44	11.82	10.00	6.80	4.03
4.	3.	3.	1.	8.11	5.74	5.46	4.53	3.11
4.	3.	3.	2.	6.69	3.23	3.19	2.89	2.22
4.	3.	3.	3.	5.05	2.17	2.18	2.07	1.69
4.	3.	4.	0.	5.72	8.25	7.00	4.77	2.82
4.	3.	4.	1.	5.47	4.57	4.29	3.44	2.29
4.	3.	4.	2.	4.60	2.72	2.65	2.33	1.72
4.	3.	4.	3.	3.59	1.87	1.86	1.72	1.35
4.	3.	4.	4.	2.83	1.38	1.39	1.33	1.09
4.	4.	1.	0.	33.57	47.07	39.51	26.62	15.80
4.	4.	1.	1.	32.57	11.52	11.59	10.92	8.68
4.	4.	2.	0.	15.57	22.32	18.75	12.65	7.49
4.	4.	2.	1.	15.07	8.73	8.46	7.31	5.27
4.	4.	2.	2.	11.95	4.59	4.58	4.29	3.49
4.	4.	3.	0.	9.57	14.07	11.83	7.99	4.72
4.	4.	3.	1.	9.23	6.87	6.50	5.34	3.66
4.	4.	3.	2.	7.69	3.90	3.82	3.43	2.63
4.	4.	3.	3.	5.87	2.65	2.64	2.47	2.02
4.	4.	4.	0.	6.57	9.94	8.37	5.66	3.34
4.	4.	4.	1.	6.32	5.54	5.15	4.10	2.72
4.	4.	4.	2.	5.38	3.33	3.22	2.80	2.06
4.	4.	4.	3.	4.25	2.31	2.28	2.08	1.63
4.	4.	4.	4.	3.41	1.73	1.73	1.63	1.33

MODEL 2

A	AB	D	DB	C	CP(1)	CP(2)	CP(3)	CP(4)
1.	0.	1.	0.	3.29	3.29	2.96	2.21	1.36
1.	0.	1.	1.	.80	.44	.47	.51	.46
1.	1.	1.	0.	6.57	9.94	8.37	5.66	3.34
1.	1.	1.	1.	1.60	1.33	1.34	1.30	1.13
2.	0.	1.	0.	8.92	8.92	7.83	5.64	3.44
2.	0.	1.	1.	2.34	1.24	1.31	1.36	1.21
2.	0.	2.	0.	3.29	3.29	2.96	2.21	1.36
2.	0.	2.	1.	1.37	.80	.85	.85	.71
2.	0.	2.	2.	.80	.44	.47	.51	.46
2.	1.	1.	0.	12.19	15.57	13.24	9.09	5.41
2.	1.	1.	1.	3.20	2.17	2.21	2.18	1.91
2.	1.	2.	0.	4.88	6.57	5.62	3.88	2.30
2.	1.	2.	1.	2.03	1.60	1.61	1.50	1.20
2.	1.	2.	2.	1.19	.88	.90	.89	.78
2.	2.	1.	0.	15.57	22.32	18.75	12.65	7.49
2.	2.	1.	1.	4.08	3.10	3.13	3.04	2.64
2.	2.	2.	0.	6.57	9.94	8.37	5.66	3.34
2.	2.	2.	1.	2.73	2.43	2.39	2.19	1.74
2.	2.	2.	2.	1.60	1.33	1.34	1.30	1.13
3.	0.	1.	0.	14.54	14.54	12.70	9.07	5.51
3.	0.	1.	1.	4.12	2.11	2.21	2.29	2.03
3.	0.	2.	0.	6.10	6.10	5.40	3.92	2.40
3.	0.	2.	1.	2.69	1.54	1.60	1.58	1.29
3.	0.	2.	2.	1.54	.83	.88	.92	.83
3.	0.	3.	0.	3.29	3.29	2.96	2.21	1.36
3.	0.	3.	1.	1.79	1.11	1.15	1.11	.86
3.	0.	3.	2.	1.11	.63	.67	.70	.60
3.	0.	3.	3.	.80	.44	.47	.51	.46
3.	1.	1.	0.	17.82	21.19	18.11	12.53	7.49
3.	1.	1.	1.	5.05	3.07	3.16	3.16	2.76
3.	1.	2.	0.	7.69	9.38	8.05	5.60	3.34
3.	1.	2.	1.	3.39	2.37	2.39	2.25	1.80
3.	1.	2.	2.	1.95	1.28	1.31	1.31	1.15
3.	1.	3.	0.	4.32	5.44	4.70	3.29	1.95
3.	1.	3.	1.	2.34	1.83	1.82	1.65	1.24
3.	1.	3.	2.	1.45	1.04	1.06	1.04	.86
3.	1.	3.	3.	1.05	.73	.75	.76	.66
3.	2.	1.	0.	21.19	27.94	23.62	16.08	9.57
3.	2.	1.	1.	6.00	4.05	4.12	4.05	3.53
3.	2.	2.	0.	9.38	12.75	10.81	7.38	4.37
3.	2.	2.	1.	4.14	3.23	3.21	2.97	2.36
3.	2.	2.	2.	2.37	1.74	1.76	1.73	1.51
3.	2.	3.	0.	5.44	7.69	6.54	4.47	2.64
3.	2.	3.	1.	2.95	2.59	2.53	2.25	1.68
3.	2.	3.	2.	1.83	1.47	1.48	1.41	1.17
3.	2.	3.	3.	1.33	1.03	1.05	1.03	.89
3.	3.	1.	0.	24.57	34.69	29.13	19.63	11.64
3.	3.	1.	1.	6.96	5.02	5.08	4.95	4.29
3.	3.	2.	0.	11.07	16.13	13.56	9.15	5.41
3.	3.	2.	1.	4.88	4.08	4.02	3.69	2.92
3.	3.	2.	2.	2.80	2.20	2.21	2.15	1.87
3.	3.	3.	0.	6.57	9.94	8.37	5.66	3.34
3.	3.	3.	1.	3.56	3.35	3.25	2.85	2.12
3.	3.	3.	2.	2.21	1.90	1.90	1.78	1.47
3.	3.	3.	3.	1.60	1.33	1.34	1.30	1.13
4.	0.	1.	0.	20.17	20.17	17.56	12.51	7.59
4.	0.	1.	1.	6.21	3.04	3.20	3.32	2.93
4.	0.	2.	0.	8.92	8.92	7.83	5.64	3.44
4.	0.	2.	1.	4.20	2.34	2.42	2.36	1.91
4.	0.	2.	2.	2.34	1.24	1.31	1.36	1.21
4.	0.	3.	0.	5.17	5.17	4.59	3.35	2.05
4.	0.	3.	1.	2.95	1.80	1.84	1.74	1.34
4.	0.	3.	2.	1.80	1.01	1.06	1.08	.92

4.	0.	3.	3.	1.29	.70	.74	.78	.70
4.	0.	4.	0.	3.29	3.29	2.96	2.21	1.36
4.	0.	4.	1.	2.11	1.37	1.40	1.30	.97
4.	0.	4.	2.	1.37	.80	.85	.85	.71
4.	0.	4.	3.	1.01	.57	.61	.64	.56
4.	0.	4.	4.	.80	.44	.47	.51	.46
4.	1.	1.	0.	23.44	26.82	22.97	15.96	9.57
4.	1.	1.	1.	7.21	4.05	4.19	4.23	3.69
4.	1.	2.	0.	10.50	12.19	10.49	7.32	4.37
4.	1.	2.	1.	4.94	3.20	3.24	3.07	2.44
4.	1.	2.	2.	2.76	1.70	1.75	1.76	1.54
4.	1.	3.	0.	6.19	7.32	6.32	4.44	2.64
4.	1.	3.	1.	3.54	2.54	2.53	2.31	1.73
4.	1.	3.	2.	2.15	1.43	1.46	1.43	1.19
4.	1.	3.	3.	1.55	.99	1.03	1.03	.91
4.	1.	4.	0.	4.04	4.88	4.24	2.99	1.78
4.	1.	4.	1.	2.58	2.03	2.00	1.77	1.27
4.	1.	4.	2.	1.68	1.19	1.21	1.16	.93
4.	1.	4.	3.	1.24	.84	.87	.86	.73
4.	1.	4.	4.	.99	.65	.68	.69	.60
4.	2.	1.	0.	26.82	33.57	28.49	19.51	11.64
4.	2.	1.	1.	8.25	5.07	5.20	5.17	4.49
4.	2.	2.	0.	12.19	15.57	13.24	9.09	5.41
4.	2.	2.	1.	5.74	4.08	4.09	3.81	3.01
4.	2.	2.	2.	3.20	2.17	2.21	2.18	1.91
4.	2.	3.	0.	7.32	9.57	8.16	5.62	3.34
4.	2.	3.	1.	4.18	3.33	3.27	2.92	2.18
4.	2.	3.	2.	2.54	1.87	1.88	1.81	1.50
4.	2.	3.	3.	1.83	1.30	1.32	1.31	1.14
4.	2.	4.	0.	4.88	6.57	5.62	3.88	2.30
4.	2.	4.	1.	3.12	2.73	2.65	2.29	1.64
4.	2.	4.	2.	2.03	1.60	1.61	1.50	1.20
4.	2.	4.	3.	1.50	1.14	1.15	1.12	.94
4.	2.	4.	4.	1.19	.88	.90	.89	.78
4.	3.	1.	0.	30.19	40.32	34.00	23.07	13.72
4.	3.	1.	1.	9.29	6.09	6.20	6.12	5.29
4.	3.	2.	0.	13.88	18.94	16.00	10.87	6.45
4.	3.	2.	1.	6.53	4.97	4.94	4.56	3.59
4.	3.	2.	2.	3.64	2.64	2.67	2.61	2.28
4.	3.	3.	0.	8.44	11.82	10.00	6.80	4.03
4.	3.	3.	1.	4.82	4.11	4.01	3.54	2.63
4.	3.	3.	2.	2.94	2.31	2.31	2.19	1.81
4.	3.	3.	3.	2.11	1.60	1.62	1.59	1.38
4.	3.	4.	0.	5.72	8.25	7.00	4.77	2.82
4.	3.	4.	1.	3.66	3.43	3.30	2.82	2.01
4.	3.	4.	2.	2.38	2.02	2.00	1.85	1.47
4.	3.	4.	3.	1.76	1.43	1.43	1.38	1.16
4.	3.	4.	4.	1.40	1.11	1.12	1.09	.95
4.	4.	1.	0.	33.57	47.07	39.51	26.62	15.80
4.	4.	1.	1.	10.33	7.10	7.21	7.06	6.09
4.	4.	2.	0.	15.57	22.32	18.75	12.65	7.49
4.	4.	2.	1.	7.33	5.85	5.79	5.30	4.17
4.	4.	2.	2.	4.08	3.10	3.13	3.04	2.64
4.	4.	3.	0.	9.57	14.07	11.83	7.99	4.72
4.	4.	3.	1.	5.47	4.89	4.74	4.15	3.08
4.	4.	3.	2.	3.33	2.74	2.73	2.57	2.12
4.	4.	3.	3.	2.39	1.91	1.92	1.86	1.62
4.	4.	4.	0.	6.57	9.94	8.37	5.66	3.34
4.	4.	4.	1.	4.20	4.13	3.95	3.34	2.39
4.	4.	4.	2.	2.73	2.43	2.39	2.19	1.74
4.	4.	4.	3.	2.02	1.72	1.72	1.63	1.37
4.	4.	4.	4.	1.60	1.33	1.34	1.30	1.13

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